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Bioenergy in Poland

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ABSTRACT

In this article we presented the current state and prospects for development of bioenergy in Poland. There are over 100 energy crop plantations of the area of at least 5 ha each, 44 pellet and/or briquette producers, over 100 biomass thermal power plants of power of at least 0.5 MW, 40 biomass and coal cofiring thermal power plants, 39 biofuel producers of capacity of 1 million dm^3/year, 80 biogas power plants located at municipal waste sites, 56 biogas power plants located at sewage treatment works, 8 agricultural biogas power plants, one municipal waste incinerator, and 46 medical waste incinerators. In the near future it is planned to further develop renewable energy based on biomass.

Contents

1. Introduction

Fire is one of the fundamental discoveries of the prehistoric era of our civilisation and the oldest way of harnessing bioenergy. Wood, vegetable oils as well as other plant resources were used to produce heat and light. This situation continued until the Industrial Revolution, since when coal and crude oil became the main energy carriers. Even though the Industrial Revolution limited the importance of biological resources as energy sources, it did not eliminate them totally [1]. Furthermore, in recent times there has been a noticeable return to bioenergy. Bioenergy is a cheap, renewable and environment-friendly energy source [2].

Poland is a country where energy is mainly obtained from coal and lignite [3]. An access to the EU imposed a duty on Poland to adjust emission parameters to those binding in all EU countries.

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Consequently, in 2001 the Ministry of Environment launched a special programme aiming at harmonization of Polish and European standards on pollution emission and percentage of alternative (renewable) energy per total electric power production in the country. This programme was named "The Strategy for the Development of Renewable Energy Sources" [4]. The strategic aim was to increase the percentage of renewable sources energy in the country fuel and energy balance to 7.5% in 2010 and to 14% in 2020 in the structure of primary energy carriers' usage.

In this article we presented the results of sociometric research describing the current state and future prospects of renewable energy in Poland, using the example of the bioenergy. For this reason the research was carried out using surveys: "The Energy Crop Plantations in Poland" [5], "The Briquette and Pellet Production in Poland" [6], "The Biomass Combustion and Cofiring in Poland" [7], "The Biofuel and Biocomponent Production in Poland" [8], "The Biogas Power Plants in Poland" [9] as well as using the data obtained directly from the bioenergy producers. This is the continuation of the survey research from 2008, when the surveys were sent to the renewable energy producers in the area of Kujawsko–Pomorskie Voivodeship [10].

2. The climate and soil conditions for plant cultivation in Poland

The climate in Poland has a transitional character between the maritime and continental climates. It happens to have years with a higher amount of precipitation, even exceeding 750 mm, and drier years with precipitation of about 500 mm [11].

It is favourable for an energy crop cultivation if that 2/3 of precipitation falls during the plant vegetation period. The duration of vegetation period, which is counted from the last spring ground frost to the first autumn ground frost, is fairly constant and oscillates between 230 days in the west of Poland to 190 days in the east. This time is sufficient for the growth and development of the most of energy plants. The daily temperature amplitude does not usually lead to any loss in biomass crop during its growth. Basing on many years of observation, monthly average of daily temperature amplitude for July is 7.1 °C. Another favourable factor is that Poland is mainly a lowland country. The majority of agricultural areas are located at the level not exceeding 300–350 m above the sea level and the slope gradient is not higher than 10° [11,12].

The soil types that cover the biggest area of Poland are podzolic and brown soils (80%). The highest accumulation of these can be found in Wielkopolska Region, Mazurian Lake District, and Podlasie Region. The alluvial or fen soils take up about 4–5% of the country area and are located in the Vistula Marshlands as well as along the following rivers: the Vistula, Odra, San, Bug, and Warta [12].

The highly fertile black-earth (chernozem) soils cover about 1% of Poland's area. They can be found in Lublin Upland and Sandomierz Basin as well as in the southern part of Kielce-Sandomierz Upland. Black soil is formed in a wet, boggy area. This type of soil takes up about 1–2% of the country area and mainly occurs in Kujawy Region. Boggy soils, which also include peat soils, cover about 9% of the country area. They are found near the rivers Biebrza and Narew in Polesie Lubelskie Region [12].

3. Biomass production in Poland

The definition of biomass which is in force in Poland is quoted in Section 2.1 of the Ordinance by the Minister of Economy and Work [13], which is fully correspondent with the definition of biomass in article 2b of 2001/77/EC Directive [14]. This definition states that "biomass is solid or liquid substances of plant or animal origin, which undergo biodegradation, substances obtained from the products, waste or remnants of agricultural and forestry production as well as of the industries processing their products, and a part of remaining waste that also undergoes biodegradation."

3.1. Waste biomass

Poland has vast bioenergy resources [15]. The best opportunities for energy production are found among cereals and rapeseed straw, agricultural and food industry waste, and forest timber waste. The General Directorate of State Forests [16] estimates that the total technical potential of forestry timber which could be directly used for energy production is about 6.1 million m^3 of wood, which is equivalent to 41.6 PJ. A high amount of this type of waste is created in the timber industry [17]. According to the analysis by the Institute of Wood Technology [18], the technical potential of waste timber from timber industry as well as from other sources can be estimated at around 58.1 PJ.

Until recently the most common method of managing waste slash was to pile it up and burn. However, this practice has been restricted since 2004 by the decisions of the General Directorate of State Forests [18]. More and more forest inspectorates have the special machines for grinding the remaining post harvesting site. Waste biomass is a rich source of nutrients for newly established plantations and could be a potential energy source as well [19].

In the recent years the Polish agriculture has been dominated by cereal crops [3], from which straw could be obtained for energy purposes. The highest crops are yielded by wheat, rye, and barley cultivations. Poland produces about 25 million Mg of straw per year. Over the decades it has been mainly used to meet the needs of animal production as a bedding material and fodder. Straw has also been used for mound covering, insulation of buildings, and bedding mats preparation in horticultural farms. Since 1983 the straw yield has been higher than the agricultural demand for it. Between the years 1983 and 1990 the annual mean surplus over the agricultural consumption was 5 354,000 Mg, and in the period between 1995 and 2001 it amounted to 10 881,000 Mg. This estimate takes into account the use of straw for skim ploughing, to maintain a stable balance of organic substances in the soil. An increase in the straw surplus meant that an effective way to manage it had to be sought [20].

One of the possible solutions was to use straw in energy production. Its calorific value is between 14.3 and 15.2 MJ/kg, which in terms of energy means that 1.5 Mg of straw is equivalent to about 1 Mg of hard coal. It is possible to use straw as a fuel not only to heat houses and livestock buildings on agricultural farms, but also in communal boiler plants [21].

3.2. Energy crop plantations

Among many energy crops that can be grown in the Polish climate, basket willow (*Salix viminalis* L.) is the most common plant to be cultivated in Poland [22] (Table 1).

Fig. 1 represents the localisation of energy crops plantations of the area of at least 5 ha in Poland. It is worth pointing out that a few tens of plantations producing biomass "for their own use" cover the area of about 1–2 ha each. The highest area designated for energy crops cultivation is in the north-west of Poland (Szczecinek region), the south-east (Zamość region), the south (Kielce, Kraków) as well as in Brodnica region [5,24,25].

Even though it is mainly common osier that is cultivated in Poland, there are also attempts to use other energy crops. For example, in Nowy Dwór Gdański (close to Gdańsk – Fig. 1), a plantation of Virginia Mallow (*Sida hermaphrodita*) was established, covering the area of 750 ha. The plantation will provide bioenergy to the

Table 1
The profitability of common osier production with density of 32,000 items/ha [23].

Item	1-Year cycle	2-Year cycle	3-Year cycle
Production cost (PLN/ha)	1355	1974	3011
Biomass crop (Mg/ha)	29	56	91
Production cost of 1 Mg of chips (PLN)	47	35	33
Price of 1 Mg of chips (PLN)	80 for each cycle		
Profit from 1 Mg (PLN)	33	45	47
Profit from 1 ha/year (PLN)	957	1 260	1 426

1 PLN = 2.89 USD (17.11.2010).

currently built municipal biomass thermal power plant of power of 10–15 MW in Nowy Dwór Gdański [24].

Virginia Mallow (*S. hermaphrodita*) is also cultivated by the Institute of Agricultural Science in Zamość (Fig. 1). The yield from one hectare varies from 12 to 17 Mg of dry mass. Mallow is also investigated in terms of using fresh biomass or silage to produce energy in the methane fermentation process [26].

At the moment, topinambur also known as Jerusalem artichoke (*Helianthus tuberosus*), Miscanthus or Amur silver–grass (*Miscanthus sacchariflorus* (Maxim.) Hack.), and Mohr's Blue Stem known as Big Blue Stem Prairie Grass (*Andropogon gerardi*) are too being investigated as well [26].

Poland is also a considerable producer of honey and bee wax. Many beekeepers use great globe thistle (*Echinops sphaerocephalus*) in two ways: as a honey-bearing plant (yield of about 600 kg of honey/ha), and after flowering and drying as an energy biomass. An asset of this plant is that it offers two harvests a year [24,26].

3.2.1. The survey research

The results of the survey "The Energy Crops Plantation in Poland" [5] indicate that the plantation areas varied from 1 to 200 ha, with the plantations of 5–20 ha being the most common. Energy crops biomass was most often collected in a 3-year cycle, with the yield within 90–130 Mg/ha. The cost of establishing plantations involved mostly the cost of the seedlings as well as expenses related to ground preparation: weeding, plant protection chemicals, labour.

The total cost of the investment depended mostly on the area and oscillated between a few tens to a few hundred thousand of PLN. Apart from own financial means, funding was often obtained from loans. In some cases, funding was provided by private or state investors, few respondents received support from the SAPARD programme [27]. The majority of energy crops plantations in Poland have been established in the years 2004–2009.

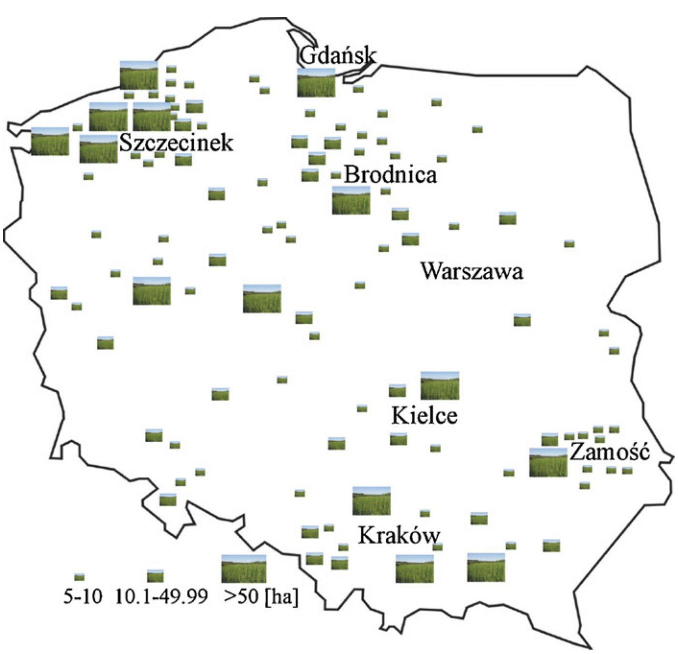


Fig. 1. Energy crops plantations in Poland (own data collation based on Refs. [5,24,25]).

Respondents to the survey "The Energy Crops Plantations in Poland" [5] are an exception among all the bioenergy respondents as they think the investment was not too expensive (some describe the costs as "moderate"). However, they indicated other problems:

- common osier not succeeded in wet areas due to unclean drainage,
- high domination of weeds over plants occured in the first year of plantation,
- damage to the seedlings done by the animals.

Respondents also commented on the problems during cultivation and biomass harvest; namely:

- plants were subject to fungal diseases,
- common osier was attacked by the pests: *Phyllodecta vittellinae*, *Phyllobius oblongus*, *Pterocomma salicis*, *Cryptorhynchus lapathi*, *Cavariella aegopodii*, *Schizotetranichus schizopus*,
- damage to the plantation done by the wild animals (roe deer, deer, wild boar, beavers, and hares),
- the lack of attested plant protection chemicals,
- warm winters making it difficult to harvest osier,
- high harvest cost,
- problems with workers for harvesting,
- the biomass market is not yet well developed,
- common osier plantation makes soil infertile (some respondents try to avoid this by using fertilisers, e.g. sewage sediment),
- the government is not interested in a development and promotion of biomass production.

The total or a substantial part of produced biomass was sold by the respondents. The buyers included local thermal power plants as well as pellet and briquette producers. Some respondents also sell seedlings whilst others produce pellets and briquettes [5].

Despite the problems with biomass cultivation and harvest, most of the respondents are planning to increase the area of energy crops. They also claim that in spite of many difficulties, the demand for biomass is growing. The respondents stated that it is important to start a new plantation or extend an already existing one only after finding a biomass buyer and signing a binding contract. The respondents stress that new investors/plantation owners face a big problem of the lack of adequate knowledge, training, and workshops on the energy crops cultivation, harvest, and financial support. For many plantation owners it has been a totally new area of business, which they have had to learn [5].

3.3. Pellet and briquette production in Poland

The pellet and briquette market in Poland has been developing quite well, which is mainly due to the requirements of

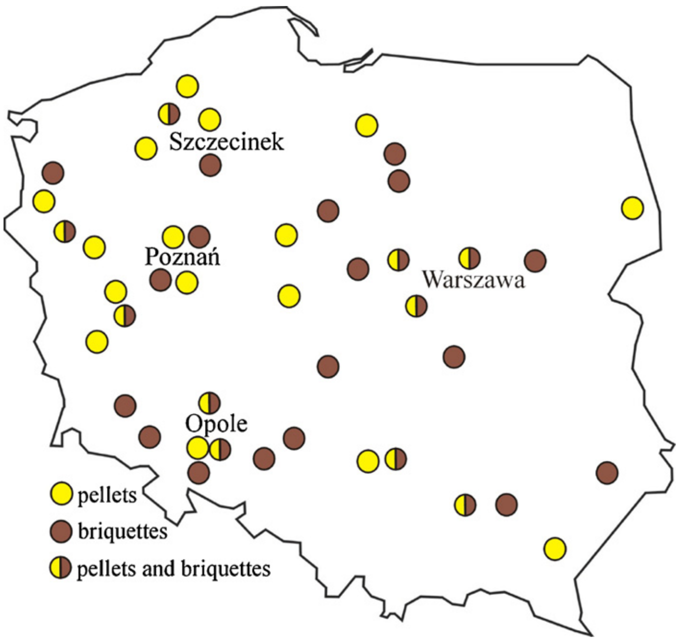


Fig. 2. Pellet and briquette producers in Poland (own data collation based on Refs. [6,30,31]).

environmental protection as well as the increasing economic competitiveness of biomass. The range of pellet and briquette application covers the following sectors: individual and municipal users as well as industrial and professional energy production. This is because pellets and briquettes can be used to power small heat-generating boilers, stoker-fired boilers, fluidised boilers as well as pulverised-fuel boiler [6,28].

Export is of high significance, for example, in 2005 over 200,000 Mg of pellets were produced, of which 175,000 Mg were exported. In spite of the increase in export of pellets and briquettes, the development of the Polish market still leaves much to be desired [28]. The lack of developed distribution network together with the lack the information about the product's price and quality means that the surplus of pellets and briquettes can be stored in warehouses in one part of the country whilst there is a demand for them in other regions [29,30].

Pellet and briquette plants are located in the areas with prevalence of forest and agricultural plantations (including energy crops). The biggest concentration of biomass producers can be found in the vicinity of Szczecinek, Poznań and Opole (Fig. 2).

3.3.1. The survey research

The respondents to the survey "The Briquette and Pellet Production in Poland" [6] state that agglomeration involved the following biomass: straw (cereal, rapeseed), sawdust, hay, straw and hay mixture, wood chips, wood shavings, shells, leaf and needle waste, energy crops biomass using the press to palletizing or briquetting by hydraulic or mechanical press.

The respondents recommend for biomass agglomeration the production lines/machines available on the Polish market. It is worth mentioning that some respondents follow their own technological ideas and carry out the process of biomass densification in the installations of their own device. Before it undergoes agglomeration, biomass is dried and broken up (e.g. by using grinding mills). A ready product is conditioned and packed. The amount of briquettes/pellets produced in 2008 was between 10 and 2000 Mg, depending on the producer.

The duration of biomass agglomeration installation realisation was mainly within 1–6 months, the investment cost varied from ca. 10,000 PLN (a stand alone pelleting machine) to a few hundred thousand PLN (the efficient briquetting machines). The money for the investment realisation came from own means or loans.

Almost all respondents stated that the main problem with the project realisation was its high cost. Other problems included [6]:

- the lack of adequate amount of raw material,
- inadequate quality of raw material,
- the absence of of the complete production lines manufactures on the market,
- high failure frequency of machines, especially the breaking-up line.

The briquette/pellet production out of biomass is still a novelty in the Polish economy. The majority of installations have been erected in recent years – 55% in 2006–2009 period. The respondents are glad with the amount of the produced biomass – in 75% of cases the amount produced met the initial investment assumptions, in 15% exceeded them, however in 10% of cases the produced amount was below the expectations. Biomass is sold to state or private industrial companies, private buyers, and public use institutions. Only a small amount is used for the producers' own needs, mainly 1–10% of produced biomass [6].

The briquette/pellet producers have reached the stage of extending their production, the majority are planning to double, and even treble the production in the near future. This goal is to be achieved using producers' own means, subsidies, and loans [6].

3.4. Combustion and cofiring of biomass

Using wood for heating purposes has been a long tradition in Poland, especially in case of burning wood in individual heat-generating boilers of low power. It is estimated that there are about 100,000 individual households equipped with wood burning, manually fed boilers; however, their power is within a few kW [32]. Biomass thermal plants are mainly located in the northern part of Poland (Fig. 3). The biggest biomass thermal plants are in the vicinity of Szczecinek as well as in Barlinek, Brodnica, Morąg, Hajnówka and Pisz. In Pisz there is the biggest biomass boiler plant – there are four POLYTECHNIK type boilers of combined power of 21 MW and efficiency of 87.4% [33]. The boiler plant uses chips, shavings, chip-shavings, woodstave, edgings, sawdust, pallet waste and common osier [34]. A similar type of biomass is used in majority of boiler plants in Poland. An example of a different fuel is cones burnt in the oil extruding plant in Białogard Forestry Inspectorate (in the vicinity of Szczecinek). Every year 300–400 Mg of cones are combusted [26].

On the other hand, the paper company International Paper (IP) Kwidzyn S.A. uses a soda recovery boiler burning boiling lye. The boiler has the heating power of 204 MW. At the same time as producing heat, IP Kwidzyn generates electric power too. For instance, in the first quarter of 2005 IP Kwidzyn produced 45,653 MWh of electric power out of biomass [24]. In Poland also dry fruit stones and cereal grain (mainly oat) are used. The cost of heating by cereal grain is twice lower than that of heating by gas, and three times lower than burning coal [35].

At the moment, there are about 250 municipal and industrial electro-thermal power stations, but only a small percentage of them have been converted to accommodate the cofiring of biomass (Fig. 3) [37]. The first fluidised boiler with a bubble layer, combusting biomass solely at a commercial scale to operate in Poland started working in 1997 in the Electro-Thermal Power Plant "Ostrołęka A" [38]. The boiler was created as a result of modernisation of a type OP-100 pulverised-fuel boiler. This boiler produces steam of capacity of 13 kg/s, the temperature of 450 °C and the pressure of 4.0 MPa. Another type of the boiler (OKF-40) was adapted to

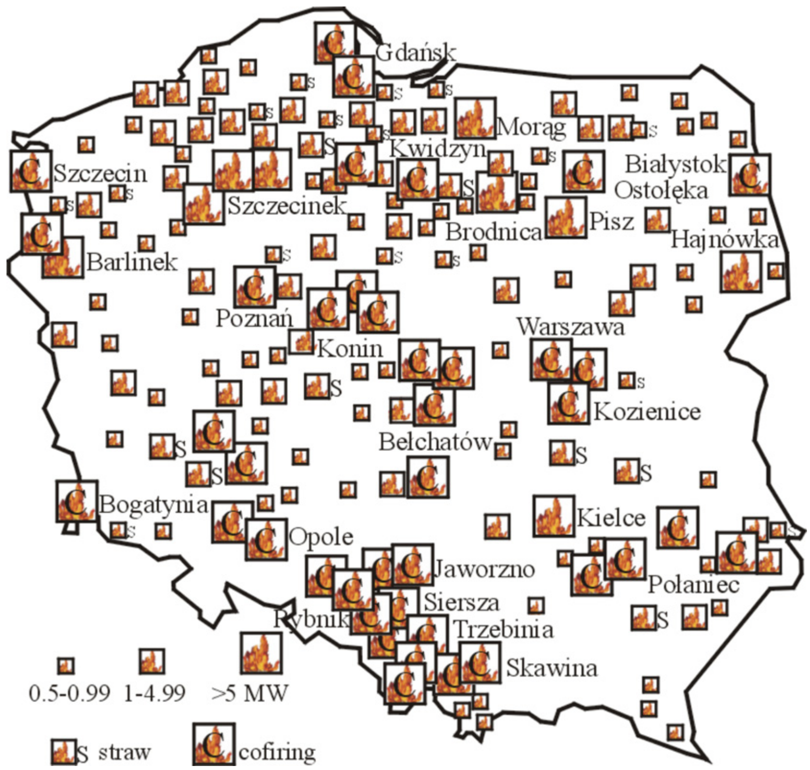


Fig. 3. Combustion and cofiring of biomass (own data collation based on Refs. [7,24,35–39]).

combust tree bark. As a result of changing the fuel the amount of ash was reduced. Moreover, this investment gave rise to: an increase in combustion efficiency by 5–7%, flexibility of boiler's operation in relation to adapting its workload so as to meet the current demand, a possibility of combusting low-quality fuels with dampness content up to 60%, utilisation from the current tree bark production and decommissioning its existing storage site as well as the lower cost of the boiler maintanance.

Apart from the Elektro-Thermal Power Plant "Ostrołęka A", biomass is also cofired together with coal in Szczecin, Białystok, Kwidzyn, Poznań, Konin, Kozienice, Bogatynia, Opole, Rybnik, Jaworzno, Siersza, Trzebinia, Skawina and Połaniec (Fig. 3). Many heating and electro-thermal power plants in Poland are planning to use biomass as a fuel on a bigger scale in the near future [39].

3.4.1. The survey research

The respondents to the survey "The Biomass Combustion and Cofiring in Poland" [7] mainly for heating use a wide range of raw materials: sawdust, wood chips, straw (rapeseed, wheat, rye, barley), hay, sunflower shells, sharps grain and wood waste from forest felling and sawmilling, wood chips from wood processing factories and furniture, grain oats, pellets and briquettes from waste wood, straw and energy crops, as well as directly to biomass energy plants. It should be noted that some of the several types of boilers burning biomass. Amount of burnt biomass varies within very wide limits: from several to over a million Mg a year.

A large variety of boilers, available on the Polish and European Union market, are used for combustion is used for burning a wide range of boilers available on the Polish and EU market. The amount of burnt biomass and yield of boiler(s) linked to the annual amount of heat produced, which ranges from several hundred to several thousand GJ. Energy is derived from predominantly (70%) is used for own needs, others partially or wholly sell it [7].

The investment cost varied from 20,000 PLN (using biomass to heat a greenhouse) to about 2–3 million PLN (large thermal plants), and was mostly covered by producers' own means and loans (sometimes money came from a few sources).

Almost all the respondents mentioned the excessive investment cost as the major problem in the project realisation. However, some of them pointed out the overgrown bureaucracy. For instance, one of the respondents mentioned that the Environmental Protection Bank requested from him to prove in a written form that straw combustion was an ecological process.

The majority of installations have been created in recent years:

- 6% before 1995,
- 14% between 1995 and 2000,
- 45% between 2001 and 2005, and
- 35% between 2006 and 2009.

The respondents were glad with the amount of produced energy – this amount meets or even exceeds the amount planned during investment preparation.

However, the biggest operational problems included:

- excessive dampness of biomass,
- insufficient number of biomass providers,
- high price of "commercial" biomass,
- high failure frequency of installations,
- the lack of specialist installation service in Poland, and
- the lack of certain spare parts.

One in three respondents is planning to increase the produced bioenergy in the near future, most of them are planning to use the European Union financial means. A few respondents are planning to obtain renewable energy from other sources (solar collectors for heating warm utility water, photovoltaic panels, agricultural biogas power stations) [7].

4. Biofuel and biocomponents production in Poland

The Act of 25th of August on Biocomponents and Liquid Fuels has been in force in Poland since 2006 [40]. This law provides a straightforward definition of biofuels. According to the Act, liquid biofuels include:

- engine petrol containing more than 5.0% of volume of biocomponents or more than 15.0% of volume of ethers,
- diesel oil containing more than 5.0% of volume of biocomponents,
- ester, bioethanol, biomethanol, dimethylether and pure vegetable oil, which are intrinsic fuels,
- biogas – gas obtained from biomass,
- biohydrogen – hydrogen obtained from biomass,
- synthetic biofuels – synthetic hydrocarbons or mixtures of synthetic hydrocarbons, produced out of biomass and being intrinsic fuels.

In Poland biofuels and biocomponents are produced on the basis of rapeseed oil (*Brassica napus* L.) and ethyl alcohol [41].

4.1. Rapeseed oil

Among the oil-bearing plants that are cultivated for consumption and motorisation purposes, rapeseed (*Brassica napus* L.) is by far the most common in Poland [42].

In the Polish climate it is possible to grow both winter and spring rapeseed. In Poland higher winter rapeseed crops are found in the areas with precipitation exceeding 525 mm per year than in the areas of lower precipitation. Winter rapeseed is not too sensitive to the lack of water in the period from shooting up until the halt of vegetation before winter. Due to its deeply reaching taproot, enabling it to access water from the deeper layers of soil, winter rapeseed can survive even 3–6 weeks of drought. In the field conditions of the Polish climate droughts are no longer than 9 weeks [11,42].

On the other hand, spring rapeseed is highly sensitive to droughts, what is related to drying and falling off of flower buds, leading to a lower crop and a lower oil content in seeds [43]. In most countries where rapeseed is cultivated, two harvest technologies are used – a set of one- and two-step [44].

There are three basic oil-manufacturing technologies, which depend on the scale of the final product yield. Big commercial oil-mills use the technology which initially presses oil by means of pug mills. The seeds were previously conditioned in a roasting plant. The second stage consists of the extraction of the remaining part of oil from pomace using a solvent (hexane or light petrol). As a result of this technology three final products are obtained: crude oil, solvent-extracted oil, and solvent-extracted cake. The indicator of oil yield obtained by this technology ranges within 0.41–0.42. The processing capacity of oil-mills using the classic method ranges between 200 and 700 Mg of rapeseed per day. The classic technology has nonetheless certain drawbacks. Solvent-extracted cake is far less likely to be used as fodder due to highly denatured proteins and solvent residue content [45]. The largest plants producing rapeseed oil for fuel purposes are located in Kruszwica and Szamotuły (Fig. 4).

The small oil-mills, of processing capacity of about 50 Mg per day, use the one-stage or two-stage method of heat pressing oil out of rapeseed grains. Before the proper process of pressing is started, the seeds are adequately crushed and conditioned. As a result crude oil and pomace are obtained. Contrary to the classic method, the technology of final heat pressing is proecological, and the pomace is much more suitable for a fodder as it contains more soluble proteins, possesses a energy value, and has no solvent residues [46].

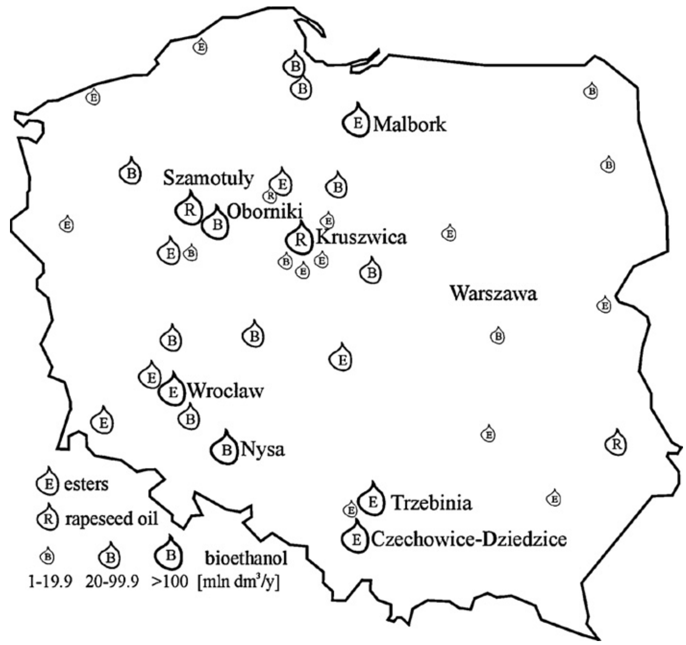


Fig. 4. Biofuel and biocomponent producers in Poland (own data collation based on Refs. [8,54]).

Very small oil-mills of processing capacity of 1–15 Mg per day, so called mini oil-mills, use the method of a final cold pressing, using one-stage or two-stages process. Prior to the pressing stage, the seeds are partially crushed and heated up to the temperature not higher than 45 °C [42].

The process of rapeseed oil production as a stock for rapeseed oil esters consists of three basic technological operations: crushing rapeseed grain, oil pressing, and oil filtering. These operations can be carried out in small oil-mills of small processing capacity; that is, 100–5000 Mg of seeds per year, as well as in commercial oil-mills of much higher capacity, reaching even 50,000 Mg per year. In the oil-mills of high processing capacity oil production out of seed is accompanied by other processes: extraction, bleaching, and further filtering [45]. In Poland the transesterification process is the most often conducted by using methanol and a base catalyst [47].

4.2. Ethanol

In 2000 there were about 900 distilleries in operation in Poland. However, their number has recently drastically fallen down to about 150. Most of the spirits are produced in agricultural distilleries, located in the areas of large potato production. The output capacity of all the distilleries in Poland is about 400 million dm^3 of ethanol per year. However, the demand for ethanol for industry and consumption purposes does not exceed 250 million dm^3/year. Therefore, there are viable reasons for adding ethanol to an engine petrol [48,49].

The Polish research into using an alcohol as a fuel dates back to the period between the World War 1 and World War 2 [50]. After the war, in the 1950s about 80 million of litres of ethanol per year for fuel blends was produced. After 1955, due to the low price of imported petrol, the production of bioethanol was abandoned. It was at the end of 1993 when bioethanol was started to be used in petrol at a bigger extent [48]. The addition of ethanol in small amounts, not exceeding 5% (V/V) meant it was possible to introduce a new petrol fuel standard PN92 C-96025 [51]. Since 1999 the revised standards, compliant with the UE standards (PN-EN228), have been in operation [52]. The total combined output capacity of ethanol dehydration plants in Poland is 700 million dm^3. Currently,

the largest bioethanol producers are located in Oborniki, Wrocław, Nysa, Trzebinia and Czechowice-Dziedzice (Fig. 4). Słupsk was the first town which introduced bioethanol as E95 petrol in 2007 [53].

4.3. The survey research

The respondents to the survey "The Biofuel and Biocomponent Production in Poland" [8] use a broad range of substrates to produce liquid fuels: cereals (wheat, triticale, rye, barley, corn), beetroots, molasses, fruit waste in case of bioethanol, and rapeseed and its oil in case of biodiesel (methyl esters).

With reference to the technology of anhydrous bioethanol production, one of the plants uses pervaporation [55], two plants follow the entrainer distillation method, whilst the remaining producers use pressure swing adsorption with molecular sieves. When producing methyl esters, the respondents use a transesterification method with a base catalyst.

The erection time of installations to produce liquid biofuel took between 8 months and 2 years. The investment cost ranged within 1–150 million PLN (some respondents did not provide the costs as these were confidential data). The money was sourced from producers' own means, loans, and subsidies [8].

The respondents mentioned the high cost and the excess of required documents as the biggest problems during investment realisation. Almost all the installations were erected or adapted to produce biofuels and biocomponents after 2004. The amount of produced fuel varies from 1 to 110 million dm^3 per year. PKN Orlen SA is the major buyer of produced biofuels and biocomponents [8].

The respondents state that the capacity reached by the installations does not currently meet the targets set during the investment stage (60% of respondents), in other cases the capacity meets the criteria. On the whole, the respondents were interested in increasing biofuel production, but they stated it would depend on the economic crisis and the development of the fuel market. An additional difficulty is posed by the lack of state support for renewable energy producers. At the moment, the legal aspects give better opportunities to the producers from outside of Poland and the EU [8].

5. Biogas production in Poland

The substrates for biogas production in Poland are the most often a raw sludge and a surplus sludge from sewage treatment plants, municipal waste (waste sites), food industry waste [56]. The first biogas plants in Poland were erected before the World War 2; however, at a bigger level they have been constructed since the 1990s. One of the first professional biogas plants located at the sewage treatment plant started operating in 1998 in Inowrocław (electric power of 320 kW, thermal power of 540 kW). On the other hand, one of the first biogas plants using a waste site gas was the installation in Braniewo (the north of Poland), which started in 1996. Gas is used there to produce heat – the installation of power of 1.3 MW provides heating and hot water for 65% of inhabitants of 18,000 – people town [57]. There is no official statistics regarding the number of biogas plants in Poland. According to the data of the Energy Regulatory Office [58] there are 87 biogas installations, but these data are restricted only to electric energy producers. According to the data presented by the Institute for Renewable Energy [59], in 2008 there were over 100 of biogas installations in operation in Poland (Fig. 5). The biogas plants that started functioning in the recent years co-generate thermal and electric power [60].

Despite a recent considerable increase in the number of biogas plants, this type of energy is still used to a small degree. In Poland there are about 1700 industrial sewage treatment plants and about 1500 municipal treatment plants, which means that only about 1% of the treatment plants use produced gas. Due to the technological aspects not all sites are able to produce biogas, but there is still the vast number of sites that could be modernised and used. The same applies to waste disposal sites – in Poland it is possible to obtain about 135–145 million m^3 of gas per year just from the municipal waste sites [57].

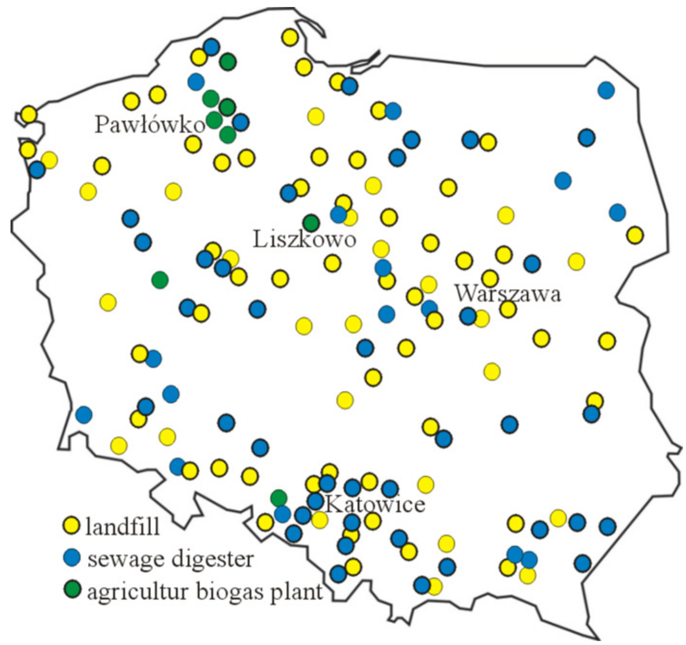


Fig. 5. Biogas plants in Poland (own data collation based on Refs. [9,58–65,67,70]).

Currently, there are eight agricultural biogas plants in Poland (Fig. 5, Table 2) [60,61]. The first agricultural biogas plant opened in June 2005 in Pawłówek. The biggest agricultural biogas in Poland of power of 2.1 MW has been operating since September 2009 in Liszkowo [62]. The potential of the agricultural sector is immense, and the full use of agricultural and food waste would considerably limit the import of natural gas.

At the moment, many research centres in Poland are investigating the effective ways of obtaining, enriching, and using biogas. An example of this is the project Biogasmax, which was described in the earlier paper [10]. The implementation of biogas plant construction programmes will ensure the energy safety, development of infrastructure, new workplaces, and an outlet for the local agricultural production. The construction of biogas plants in Poland is turning into a merely business enterprise, which is profitable for the investors, construction companies as well as for the agricultural and food sector, and stock providers for biogas production [66–70].

5.1. The survey research

The majority of biogas bioenergy producers [9] generate both thermal and electric power. In 2008 this amounted to between a few and a few thousand of MW of electric energy and from a few to a few ten thousand GJ of heat per year. The construction of biogas plants took between 6 months and 2 years, and the investment cost in most cases was higher than 1 million PLN. As for biogas plants, in almost every case the financial means came from a few sources. Apart from producers' own means, money was sourced from loans (often from National Fund for Environmental Protection and Water Management), the European Union structural funds (e.g. Cohesion Fund), means from a particular town's budget, means from Integrated Operational Programme for Regional Development, Regional Fund for Environment Protection

Table 2
Agricultural biogas plants characterisation in Poland (own data collation based on Refs. [58–65]).

No.	Place	Opening year	Electrical power (MW)	Thermal power (MW)	Substratum
1.	Pawłówko	2005	0.940	0.980	Slurry, slaughter waste, horn silage, glycerol
2.	Płaszczyca	2008	0.625	0.692	Slurry, horn silage, waste processing plant
3.	Kujanki	2008	0.330	0.350	Slurry, waste processing plant
4.	Koczała	2009	2.126	2.176	Slurry, horn silage, glycerol
5.	Liszkowo	2009	2.126	2.400	Distilerry brew, vegetable waste
6.	Kalsk	2009	1	–	Slurry, horn and sorgo silage
7.	Studzionka	2010	0.030	–	Chicken litter, slurry
8.	Nacław	2010	0.625	0.680	Slurry, horn silage, glycerol

and Water Management, Phare and Thermie funds, and private investors' means. Most of the biogas plants were built within the last 5 years [9].

As the biggest problems during investment, the respondents mentioned the high cost and, in some cases, difficulties related with connection to the power network. The current capacity of biogas plants meets the targets set at the investment stage (90% of respondents), in few cases it either exceeds or does not meet the initial goals. Most of biogas plants (77%) sell (a part or the total of) produced energy first of all to a state energy company, and in a few cases to private companies. Power for their own use is mainly utilised by biogas plants functioning at sewage treatment sites. Half of the respondents are planning to increase the amount of produced biogas (mostly 20–40%) in the near future, taking full advantage of the European Union funds. Respondents state that the constant changes in tax law pose the major problem for planning or extending their investment [9].

6. Other sources of bioenergy in Poland

In Poland bioenergy is also obtained by means of organic waste combustion in medical waste incinerators and, to a smaller degree, in municipal waste incinerators. At present, there is one municipal waste incinerator in Poland located in Warsaw (almost 60,000 Mg is burnt there per year). In the near future, new incinerators are to be opened in: w Łódź (250,000 Mg), Kraków (250,000 Mg), Warsaw (265,000 Mg), Białystok agglomeration (100,000 Mg), Trójmiasto agglomeration (250,000 Mg), Śląsk agglomeration – Ruda Śląska (250,000 Mg), Śląsk agglomeration – Katowice (250,000 Mg), Poznań (200,000 Mg) and Szczecin Metropolitan District (180,000 Mg) [71,72].

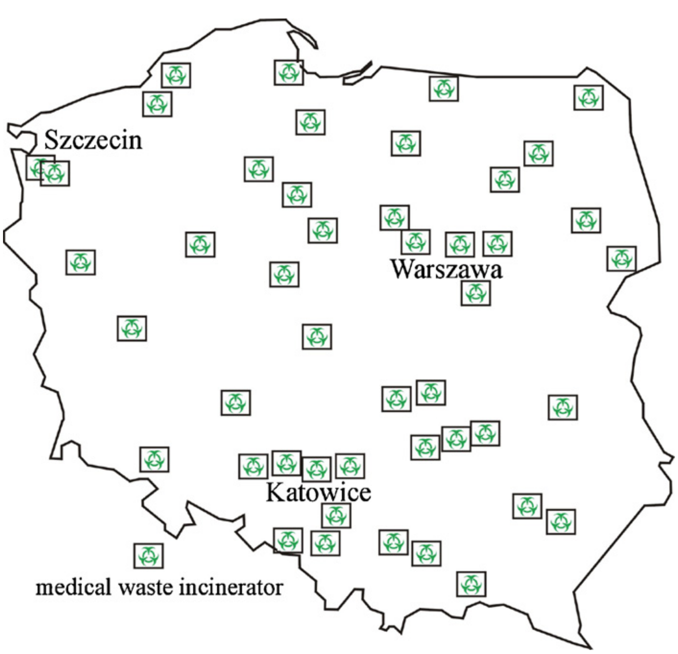


Fig. 6. Medical waste combustion in Poland (own data collation based on Refs. [76]).

The medical waste considered as dangerous cannot be recovered according to the Minister of Health Decree of 23rd of December 2002 [73] on types of medical and veterinary waste, the recovery of which is forbidden. Therefore, this type of waste is subject to different techniques that render it harmless such as: thermal processing, autoclaving, thermal dissinfection, exposure to microwaves as well as physical and chemical processing [74,75]. The most common method of rendering waste harmless is to subject it to thermal processing; that is, waste is burnt in special incinerators that recover heat. In Poland there are 46 medical waste incinerators, mostly located in large cities [75,76] (Fig. 6).

7. Conclusions

As an agricultural country Poland should develop technologies based on biomass, biofuels, and biogas. The prospective investors in Poland are discouraged by high investment costs of renewable energy technologies, high cost of investment preparation in relation to running costs as well as the lack of precisely defined economic and tax mechanisms in the state budget and financial policy. Moreover, the lack of defined strategies, programmes and harmonogram of spending money from ecological and parabudget funds put off the investors and make it more difficult for the sector to develop with the lowest costs. In their response to the survey many people stress the lack of sufficient support from the authorities as well as training and workshops for bioenergy producers or extensive marketing. Despite many difficulties, bioenergy producers in Poland are planning to increase their activity in the forthcoming years. The installations using the renewable energy sources are local by nature and do not require centralised technological infrastructure. These small and scattered technologies naturally fit in with the European Union as well as the local and regional policy, strategy and development plans.

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